User’s Guide for the GOES DCS

Random Reporting Channel

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Prepared for the

National Oceanic and Atmospheric Administration

EXECUTIVE SUMMARY

NOAA's Data Collection System, or DCS, onboard GOES satellites is capable of monitoring and reporting significant environmental events in real-time through the use of the random reporting DCP message type. Successfully implementing this type of DCP message requires coordination and cooperation between NOAA, the DCS equipment vendor, and the DCS user community. This user's guide was first published in 1980 when the technology involved was emerging, and best practices had yet to be established. Now, 40 years later, with extensive experience operating DCS platforms transmitting random reporting messages, NOAA has revised the user's guide to provide recommendations to DCS vendors and users alike that outline the best practices for implementing e platforms configured to transmit DCS random reporting messages.

This user's guide begins by presenting the background and general information about the DCS random reporting message type. Random reporting performance is then discussed with the help of both the analysis of, and metadata from, actual random reporting message transactions, and the information is presented in an easy-to-understand format. In depth analysis, including the theory and math behind the random reporting message type is presented in appendices for those who are interested.

The recommendations made in this user's guide include details on how to configure a DCP to transmit random reporting messages with a high probability of success, expeditious delivery of messages, and how to best use this valuable shared resource.

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Chapter 1: Introduction

1.1. Overview

The National Oceanic and Atmospheric Administration (NOAA) Geostationary Operational Environmental Satellite (GOES) is operated by the National Environmental Satellite, Data and Information Service (NESDIS) division of NOAA and includes a payload that relays scientific data and telemetry data transmitted from terrestrial-based environmental monitoring stations in the western hemisphere. The payload is called the Data Collection System (DCS) and the stations are referred to as Data Collection Platforms (DCPs). The specifications that dictate how DCPs are to be operated are maintained by NOAA, and the DCS vendors and user community, in a set of standards called the GOES DCS Certification Standards (CS). The current version of the standard is Certification Standard Version 2, or CS2, and was ratified in June of 2009 (NOAA 2009).

The messages transmitted from DCPs can be one of three types. The most common message type is the self-timed message. These are messages that are sent on a specific channel, at a specific time, and on a repeating schedule. Transmissions can use either 300 bits-per-second (bps) or 1200 bps data rates. Typical DCP configurations transmit self-timed messages once per hour in a 5-15 second time window.

The second commonly used type of DCP message is the random reporting message that is the focus of this user's guide. These messages occur randomly in response to a triggering event experienced by the DCP, and are most often used to respond to environmental events and relay the associated scientific data prior to the next scheduled self-timed message. They are also sent without an acknowledgement of having been received. It is this form of data message that is the subject of this user's guide.

The third DCP message type is the two-way message. This is a new form of message that is currently under development by the NESDIS DCS team. Once implemented, this message type will create a two-way link with remote DCPs for management purposes. The capability of having DCPs not only transmit messages with environmental data, but also receive command messages, is intended to enhance the transmissions the of self-timed and random reporting message types by permitting the control of DCPs via remote communications. It will be possible, for instance, to remotely re-program, re-configure or shut-off a DCP that is transmitting incorrectly and interfering with other DCPs.

1.2. Random Reporting

The principal advantage of supporting the random reporting DCS message type is the opportunity to report events more quickly, and with a temporary higher frequency, than self-timed reporting permits. The principal challenges random reporting are that the report time for the message is not deterministic, and that DCPs must share the channels assigned for random reporting in a peer-to-peer user profile where no DCP is given preference. As a result, the probability of success when receiving a random report message is limited by the existing random reporting activity on the channel.

The DCS system consists of 400 kHz of spectrum with approximately 330 kilohertz (kHz) of contiguous spectrum that is divided up into discrete channels for either 300 bps or 1200 bps operation. The 300 bps channels are 750 Hertz (Hz) wide, while the 1200 bps channels are 2250 Hz wide. Random reporting can use either data rate, however, only 300 bps channels are currently assigned for random reporting, and no 1200 bps channels are assigned for random use. Channels currently configured for random reporting are listed in the left column of Table 1.

The CS2 specifications require that all random reporting messages be transmitted in a maximum time of 3 seconds for 300 bps operation, and 1.5 seconds for 1200 bps operation. Besides the scientific data transmitted in a random reporting message, the CS2 standard requires all transmissions from DCPs to include formatting and synchronization information to facilitate reception. This message overhead establishes a minimum duration for a random reporting message of approximately 0.8 seconds for 300 bps operation, and approximately 0.3 seconds for 1200 bps operation. Again, it should be noted that 1200 bps random reporting is not currently configured or allocated for any DCS user.

Most DCS users implement self-timed reporting as their primary method for transmitting the platform's data. Users who do chose to implement random reporting usually do so with it assigned as the secondary form of DCS messaging. Table 1 indicates the number of DCS users on each channel with either primary or secondary assignments for random reporting, as assigned in November 2020. The table clearly shows random reporting is most often used as a secondary form of DCS messaging.

1.3. Why a User's Guide?

Random reporting is a powerful tool in the DCS system but its success depends on DCS vendors and users implementing random reporting with best practices to ensure that channels assigned for random reporting function as a shared resource that is equally available to all assigned users. These best practices were not codified in the original certification standards because they had not been established. While that may change at some point in the future, for now, operating DCS random reporting successfully remains a coordinated effort for NOAA, the DCS vendors, and the DCS users. This user's guide explains those best practices through recommendations, summarized here in the introduction, and presented in detail in Chapter 2, Recommendation Summary. The origin of these best practices is provided by in-depth technical appendices for those curious stakeholders who wish to investigate the math and theory supporting the recommendations. The additional chapters include a discussion on the variations in how random reporting is implemented in DCPs by vendors in Chapter 3, detailed discussion of the performance of the current random reporting scheme in Chapter 4, and finally a discussion on how random reporting data and self-timed data is disseminated by NOAA in Chapter 5.

Table 1: Random Reporting Channel Assignments – October 2020

Random Channel Number	Number of DCPs Assigned P = Primary Assignment S = Secondary Assignment
104	15P + 25S = 40
114	0P + 159S = 159
115	0P + 1338S = 1338
118	0P + 1429S = 1429
119	0P + 1565S = 1565
120	0P + 202S = 202
121[1]	0P + 1207S = 1207
123	0P + 585S = 585
124	0P + 1086S = 1086
125	0P + 2681S = 2681
126	20P + 1402S = 1422
127	0P + 1628S = 1628
128	0P + 1159S = 1159
129	0P + 1428S = 1428
130	0P + 2899S = 2899
131	1P + 2121S = 2122
132	2P + 1380S = 1382
133	0P + 1162S = 1162
134	50P + 6S = 56
135	0P + 1131S = 1131

[1] At the time this report was written, channel 121 was experiencing interference that corrupted its recorded data. This channel was ignored for the analysis in this report.

Chapter 2: Recommendation Summary

The successful operation of the DCS random reporting channels requires cooperation from the DCS users. The random reporting configurations that users implement in their DCPs must conform, as closely as possible, to the optimum settings listed below. If all DCS users follow these recommendations, then NOAA can continue to provide high probabilities of success that all DCS random reporting messages will be delivered.

Recommendation 1: Follow the NOAA DCS CS2 requirement for transmit duration. Section 2 of the CS2 standard requires that all random reporting messages are transmitted in no more than 3 seconds for 300 baud operation and 1.5 seconds for 1200 baud operation.

Recommendation 2: After a triggering event occurs, wait a random interval of time before initiating the first random message. The interval can be implemented with a Poisson distribution utilizing a message transmission rate of no faster than once per hour, or it can be implemented with a fixed plus random interval of no shorter than 5 minutes, plus a random interval of +/- 1 minute determined by a uniform distribution. The combined fixed plus random interval would therefore range from 4 to 6 minutes in length. For users with near-real-time reporting requirements, it is appropriate to consider reducing the initial delay between the triggering event and the first random message transmission, e.g., to a 2 ½ minute fixed plus a 30 second random interval. In addition, for users that reduce their self-timed message interval significantly, e.g., to 15 minutes, still desire to maintain the use of the random reporting channel, it is appropriate to reduce the random reporting delay interval between redundant messages, e.g., 2-3 minutes instead of 4-6 minutes.

Recommendation 3: Send no more than three copies of the original message and separate them in time at fixed plus random intervals from the initial message, and from each other. The interval can be implemented with a Poisson distribution utilizing a message transmission rate of no faster than once per hour, or it can be implemented with a fixed plus random interval of no shorter than 5 minutes plus a random interval of +/- 1 minute determined by a uniform distribution. The combined fixed plus random interval would therefore range from 4 to 6 minutes in length.

Recommendation 4: Use only 300 baud for random channel operation. The use of 1200 baud random reporting is permitted by CS2, however it is not recommended to do so and, to date, no users have been assigned to operate on a random reporting channel at 1200 baud. All users implementing random reporting on their DCPs currently use 300 baud. When compared on a transaction basis, 300 baud random reporting uses less of the available DCS channel resources than 1200 baud operation. Consider that 300 baud random reporting messages can be as long as 3 seconds but 1200 baud random reporting messages must be no more than 1.5 seconds long. This would suggest that for every random message sent at 300 baud, it would be possible to send twice that number of messages if we use 1200 baud. Unfortunately, 1200 baud random channel operation requires three times the channel bandwidth that 300 baud operation requires. So while random messages are half the duration and quadruple the data rate with 1200 baud, they require 3 times the bandwidth that 300 baud requires; i.e. in place of every 1200 bps channel, three 300 bps channels can be assigned. This yields a net disadvantage of platform utilization, and only a 45% improvement effective data rate for 1200 baud random channel operation as compared to 300 baud operation. Taking into account the overhead portion of a DCS message, the maximum number of data bytes in a 1.5 second 1200 bps is 172 as compared to 79 bytes for a 3 second 300 bps message. Therefore 3 seconds of 1200 bps transmissions (i.e. two 1.5 second messages) can deliver 344 bytes on a single channel, but three 3 second 300 bps messages on different channels (i.e. from different platforms) can deliver 237 bytes.

Recommendation 5: If a DCS user reduces self-timed message intervals significantly for a particular DCP, for example, down to 5 minutes, consider terminating the use of random reporting. Many DCS users benefit from random reporting as a tool to provide data from DCPs during the 1-hour interval between standard self-timed messages. If the self-timed interval is reduced, some users have indicated they will no longer require random reporting. Since DCS channels are a valuable satellite resource, reducing number of DCPs requiring random reporting would allow NOAA to reassign some random channels for self-timed use and expand the number of available assignments for self-timed transmissions.

Chapter 3: Operation Variations

There are several variations in the DCP random channel configuration parameters that vendors make available in their DCP products for DCS users. Early in 2021, vendor surveys were conducted by NOAA for this report and the results are summarized here.

All of the vendors who responded indicated that they implement repeated transmissions of the original random reporting message. Three vendors permit the number of messages to be configured. The ranges varied from 0 to 99 copies with 3 copies being the default for two of the three vendor's products. One vendor's DCP transmits three repeated copies, while another vendor transmits only one copy per random reporting sequence.

All responding vendors also reported that they can support configurable interval durations between messages and repeated copies of the message, and can range from 0 minutes to 24 hours. The shortest default setting for the interval reported by vendors is 2 minutes, with the next shortest default interval being 5 minutes. This survey question did not specifically ask about any random component to the interval, so it is not known how vendors generate randomness for the interval

All vendors indicated they implement a delay after the triggered event occurs before transmitting the original random reporting message.

All vendors reported that the interval between transmissions includes a random component.

Chapter 4: Random Channel Performance

4.1. Discussion

When a triggering event initiates a random report through DCS, a specific sequence of steps is initiated by the DCP that will send the report. The sequence that is typically used is based on the research conducted for the original user's guide for random reporting that was written in 1980 (NOAA 1980). While this sequence is not required by the current DCS standards it is the most widely used sequence.

The sequential steps are listed in Table . They are also presented in timeline form in Figure 1 to help explain how the steps and programmed delays interact to create a complete random reporting transaction. Note that the transmission times have a duration that is much shorter than the interstitial program delays that occur between transmissions. There is currently no requirement to limit the number of transmissions in a transaction so the sequence can continue until terminated by the DCP.

Table 2: DCS Random Reporting Transaction

Step	Description	Execution Time (seconds)
0	Triggering event	0 sec
1	Triggering event program delay	240-360 sec
2	Message Transmission	0.75 – 3 sec
3	Transmission Program Delay	240-360 sec
4	Message Transmission	0.75 – 3 sec
5	Transmission Program Delay	240-360 sec
6	Message Transmission	0.75 – 3 sec
7	Additional Transmission Program Delays……	240-360 sec
8	Additional Message Transmissions……	0.75 – 3 sec

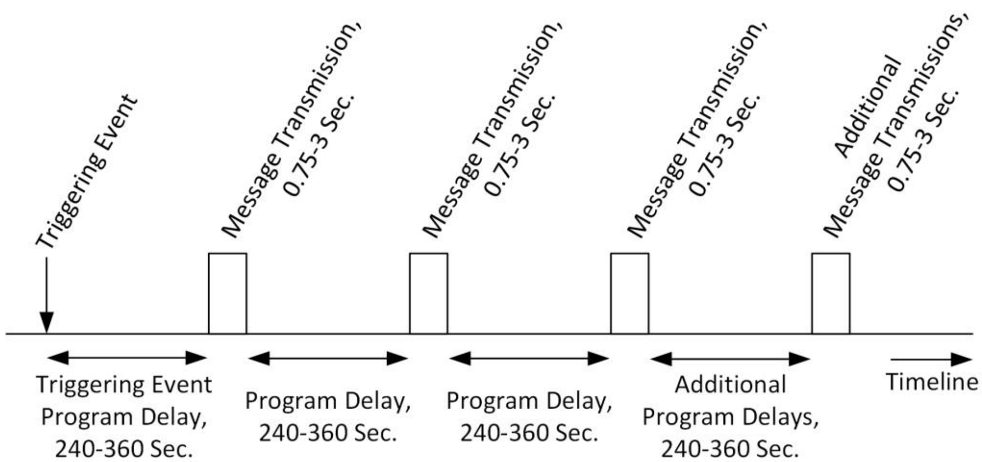

Figure 1: Random Reporting Transaction Timeline

The first step in a random reporting transaction is a delay following the triggering event that is intended to ensure that any other DCPs experiencing the same event will not transmit their initial message at the same time. The delay includes a 5-minute fixed delay, followed by an additional random delay component of +/- 1 minute. This creates a 2-minute window, centered on a delay of 5 minutes, during which the initial message will be transmitted. The transmission is step two in the transaction.

Once the initial message is transmitted, redundant messages are transmitted sequentially, each after an additional delay has expired. This redundancy is an important key to the success of the random reporting channel. Even though there was a singular triggering event, a DCP can send any number of redundant messages in response to a singular, triggering event. In this guide, we designate the number of redundant messages transmitted for the singular event by the variable ‘r’. The additional delays for redundant messages are computed separately, using the same metric as was used for the initial delay. The additional redundant pairs of delays and transmissions make up steps 3 through 8 in the random reporting transaction sequence example outlined in Table 1.

If, for instance, 4 redundant messages are transmitted, then the entire random reporting transaction can take as few as 963 seconds (just over 16 minutes) to complete or as many as 1452 seconds (just over 24 minutes). The actual duration depends mostly on the random delay components of each sequential program delay. It is important to note that more often than not, the message will be delivered successfully by the first transmission. The redundant transmissions are included in the sequential steps to increase the probability of successfully receiving a random reporting message.

If a DCS random reporting channel had only one active DCP assigned to it, then when a triggering event occurred, the initial message and all redundant message transmissions would be received reliably with minimal errors caused only by random noise. However, as discussed in the first chapter, each random reporting channel has multiple DCPs assigned to it that can initiate a random reporting transaction at any time. This means that the transmissions from other DCPs using the channel may overlap in time and interfere with each other, preventing both messages from being received. By requiring program delays with random components between message attempts, the DCPs will be less likely to interfere again during each of their next repeat transmissions.

The sequential steps used to complete a DCS random reporting transaction are designed to ensure that the probability of successfully delivering at least one of the transmitted messages associated with a triggering event is maintained at or above 95%. This is accomplished through several important characteristics of the random reporting system:

- The rate at which triggering events occur is expected to be infrequent. Rates on the order of once per day or once every few hours, ON AVERAGE, are expected. DCS random reporting users should not transmit random messages at a rate that could be supported by self-timed messages.

- Random reporting message duration must be kept short to minimize the chance of collision between messages from independent DCPs. In fact, the current CS2 specification requires that random reporting messages transmit for no more than 3 seconds.
- The number of random reporting DCPs assigned to a channel must be maintained below a maximum count that will support the expected total rate of triggering events for that channel, while ensuring the desired 95% probability of successfully delivering a message.

There are several parameters that are needed to understand the performance of a random reporting channel. The first parameter is the rate at which triggering events occur, and is also known as the original message transmission rate. The rate is expressed as the number of events that occur during some convenient block of time, for example one second or one hour. When a triggering event occurs in reporting scheme, the complete message transaction that results will usually include the transmission of multiple messages comprised of the initial original message and redundant versions[2] of the message. This means the total message transmission rate for a random reporting DCP is higher than its original message transmission rate.

There is an important restriction on the original message transmission rate that must be discussed. This restriction is necessary for the communication system to work and for the mathematical analysis to be valid. For a DCS random channel to function, the channel message rate must never be allowed to exceed the capacity of the channel. Consider the example that all of the DCPs transmit original messages of 3 second duration (with no redundancy) and that they are coordinated so that there is no idle time on the channel. In that case, the highest possible message rate for the entire channel is 1 message every 3 seconds. If, in this example, there are 100 DCPs on the channel, all equally sharing the capacity of the channel, and still coordinated, then the highest possible message rate for any individual DCP is 1 message every 300 seconds. Should one or more DCPs violate this restriction the message rate would increase beyond the capacity of the channel. This will result in collisions on the channel and invalidate an important assumption used to analyze the performance of the channel.

In the actual DCS system, there are multiple DCPs all capable of sending a multi-message, random reporting transaction. As a result, the total number of messages that will be transmitted onto the channel is more than the total event-based rate of transmission. All of the messages that are sent by all of the DCPs on a particular channel place a load on that channel. We define channel loading as the sum of all attempted message transmission time durations in

[2] Many DCPs will actually take the opportunity to update the sensor data contained in the repeated messages. This ensures that the data communicated in the random report will be the most up to date data possible, even if one of the repeated messages is the one received successfully.

our convenient block of time. Mathematically it is defined as the product of the total message transmission rate multiplied by the average message duration. Keep in mind that the messages used to compute the channel loading may or may not overlap causing interference when they do.

Since we are interested in knowing how successful we are utilizing each random reporting channel, we can extend the analysis to determine the throughput of the channel. Consider the example of any channel supporting a message transmission rate of one message every 2 seconds. If the messages are 2 seconds long then the channel will be fully utilized if it can deliver all of those 2 second messages by sending them one after the other with no idle time in between. We define the throughput for a DCP random message channel as the product of the triggered event rate, or message transmission rate and the message duration time. This quantity can never be greater than one and is usually quite small (often less than 0.15 or 15% throughput). In the case of the DCS random reporting channels, we are using some of the channel resources to send repeated copies of the original message. This means that the DCS random channel throughput will never reach its maximum possible value of one.

When all of the random transmissions in the sequence fail to be delivered, then the transaction is concluded without delivery of the random reporting message. If this happens, on average, no more than five times for every 100 triggered events, we have achieved a probability of successful message delivery for the random reporting channel of 95% or better. All of these parameters: probability of success, transmission rates, and channel loading are shown to be interrelated, and the technical details of these relationships are presented in the appendices.

4.2. Predicted Performance

The performance of a DCS random reporting channel can be predicted by applying a combination of queuing theory, probability and statistics. The details of this application that produced the results outlined in this section can be found in the appendices at the end of the guide. The first performance parameter to review is the probability of successful for completing a random channel transaction. In the most common configuration, the transaction includes an original message and multiple copies of the original message, sent in a sequence with random periods in between to avoid collisions with other messages from other DCPs. The copies add additional communications traffic to the channel, and we find that the probability of success can be expressed as a function of this total traffic or channel loading. The graph in Figure 2 demonstrates this relationship for a random channel.

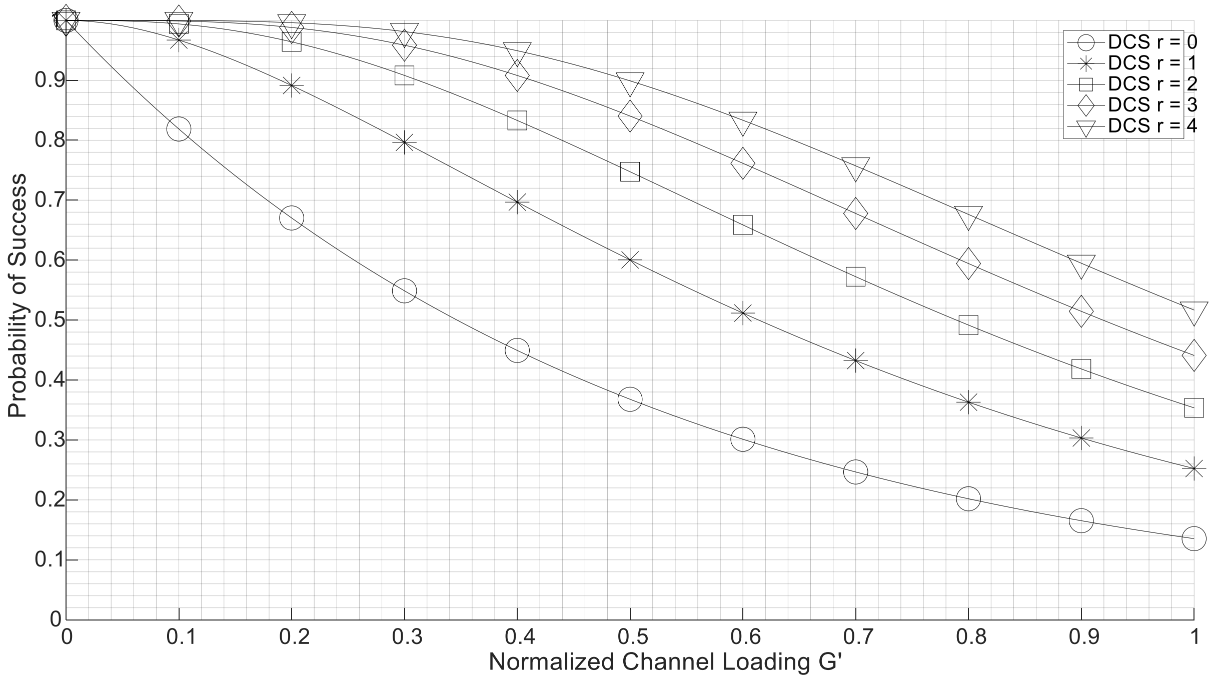

Figure 2: Predicted Random Channel Probability of Success

There are multiple curves to demonstrate how the relationship changes as we add additional repeated copies of the original message. We note first that any number of repeated copies from 0 to 4 can provide any desired high probability of success, such as 0.95 or 95%. However, the low channel loading necessary for this success will dictate that some repeated messages be utilized. If, for instance, no repeated messages were sent, the channel loading would need to be very low to maintain 95% success, and this would in turn mean the number of permitted DCPs on the channel would be very low. The impact of the low channel loading can be seen in Figure 3 containing a graph that plots throughput for the DCS random channel as a function of that channel loading. As with probability of success vs. loading, it consists of a family of curves demonstrating how the channel throughput changes when an increasing number of redundant messages are sent.

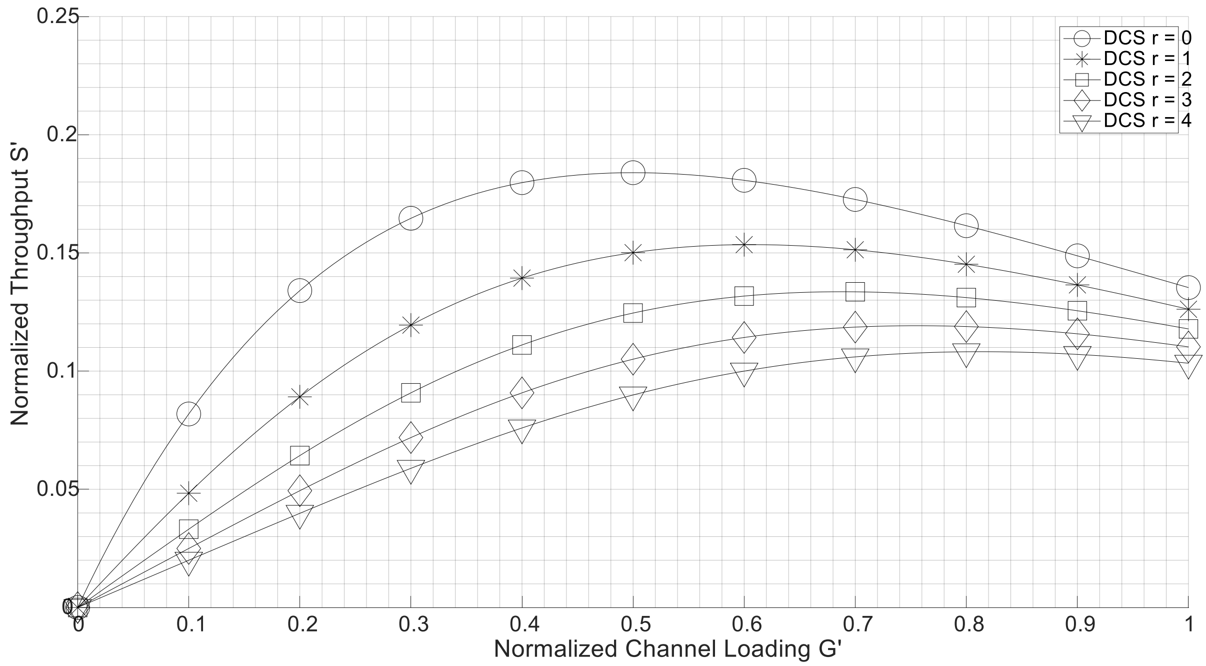

Figure 3: Predicted Random Channel Throughput

We note that while not sending any repeated messages will allow us to maximize throughput, it occurs at a value for channel loading with a low probability of success. In fact, we can analyze the five values of r shown in the two plots and determine which value of r yields the highest throughput, while maintaining a 95% probability of success for delivering the message. The results of this analysis are shown in Table 2. For each number of repeated messages, the channel loading that supports a 95% probability of success is first determined and then used to find the matching throughput. The throughput associated with 3 repeated messages is the highest.

Table 3 also includes the total message transmission rates, $\boldsymbol{\lambda_t'}$**,** which includes the repeated messages, as well as the original message transmission rate, $\boldsymbol{\lambda}$**.** Both rates are for the channel, and not an individual DCP. We note again that the highest original message rate, assuming a 95% probability of success, occurs for the scenario where 3 repeated messages are transmitted. The original message transmission rate for the channel, $\boldsymbol{\lambda}$**,** can be considered as simply the product of the number of DCPs on the channel and their average, per-DCP, transmission rate[3]. This allows us to consider combinations of high and low numbers of DCPS, alongside high and low individual DCP transmission rates. In Table 4 below, combinations of the maximum number of DCPs, along with its corresponding transmission rate are presented for the five values of ‘r’. Note again that for a specific transmission rate, the maximum number of DCPs will be

[3] The appendices discuss the assumption required for this prediction, namely that all DCPs must be assumed to have the same average transmission rate.

supported if 3 copies of the original message are transmitted for each random report transaction.

Table 3: Optimum Number of Repeated Messages

Assuming $P_s' = 95\%$				
Number of Repeated Messages	**Normalized Channel Loading G'**	**Maximum Normalized Throughput S'**	**TX Rate λ_t' w/ τ = $3\ \mathrm{sec}$**	**TX Rate λ w/ τ = $3\ \mathrm{sec}$**
r = 0	0.025	0.0238	0.0083	0.0083
r = 1	0.126	0.0599	0.0420	0.0210
r = 2	0.229	0.0725	0.0763	0.0254
r = 3	0.320	**0.0760**	0.1067	**0.0267**
r = 4	0.398	0.0756	0.1327	0.0265

Table 4: Number of DCP Message Sources per Channel at $P_s' = 95\%$

$\tau = 3\ \mathrm{sec}$	**Maximum Number of DCPs Per Random Channel**				
Individual DCP λ_n Messages/Hour	**Channel $\lambda = 29.9$ Messages/Hour With r = 0**	**Channel $\lambda = 75.6$ Messages/Hour With r = 1**	**Channel $\lambda = 91.4$ Messages/Hour With r = 2**	**Channel $\lambda = 96.1$ Messages/Hour With r = 3**	**Channel $\lambda = 95.4$ Messages/Hour With r = 4**
0.006 (1/wk)	4980	12600	15240	16020	15900
0.021 (1/48hr)	1423	3600	4354	4577	4543
0.041 (1/24hr)	729	1844	2230	2344	2327
0.083 (1/12hr)	360	911	1102	1158	1149
0.167 (1/6hr)	179	453	548	576	571
0.25 (1/4hr)	120	302	366	384	382
0.5 (1/2hr)	60	151	183	192	191
1 / hr	30	76	91	96	95
2 (1/30min)	15	38	46	48	48
3 (1/20min)	10	25	30	32	32
4 (1/15min)	7	19	23	24	24

4.3. Measured Channel Performance

To measure channel performance and make comparisons with the results provided by theory and simulation, queries were performed on DCP message data accumulated during a four-month period between August and December of 2020. Individual messages were processed in hourly segments to determine the average message time and length, which was then used to determine the channel metrics generated by the query. For those interested, the full details on the query algorithm used to generate the channel loading, throughput, and probability of success for each random DCS channel can be found in Appendix 5.

Before moving on, it should be noted that the measured performance derived from actual DCS message data may not exactly match the output predicted by theory, and that the analysis only considers the base case where no repeated transmissions occur. To simplify the analysis, the queries consider each message as a distinct element, where-as the theory considers the original message plus any repeats as distinct elements. In addition, a cursory review of the data revealed there is little consistency in how random transmissions occur between platforms, and so implementing queries to include repeated messages is not a trivial task. Determining if a message is the original, and how many repeats were associated with it, would require many assumptions about the messages that may or may not be true, which could skew the calculated metrics. As a result, the only comparison made between predicted and measured channel performance is for the base case where it is assumed that each triggered random transmission has no repeated transmissions ($r = 0$).

The results of the performance analysis indicates that the measured random channel performance appears to closely track the performance predicted by theory. Unfortunately, a channel loading of just over 6% is currently the highest value for the random channels analyzed. As a result, there are limited data points that only range from 0.0 to 0.1 (0 to 10%) loading for direct comparison with the predicted channel loading and throughput vs. probability of success presented in Figures 2 and 3. Despite that limitation, regression analysis performed on the data shows that the measured performance metrics closely track what theory predicts for the case where zero repeat transmissions are performed ($r = 0$). Figure 4 below is a plot of the measured probability of success vs. channel loading for the channels included in the analysis. An exponential regression performed on the data produced a trend line that is very close to what theory predicts for all values of channel loading. Figure 5 below is a plot of the measured throughput vs. channel loading for the channels included in the analysis. Unfortunately, there are not enough data points available to perform a strong regression analysis that mirrors what theory predicts for all values of channel loading but a 2^{nd} order polynomial regression does fit nicely up to a channel loading of about 20%.

The channel data in Tables 5 and 6 of this chapter were used to determine the loading and probability metrics from which Figures 4 and 5 are generated. When compared with theoretical predictions in Figure 2, it is evident that the measured probabilities are a very close fit.

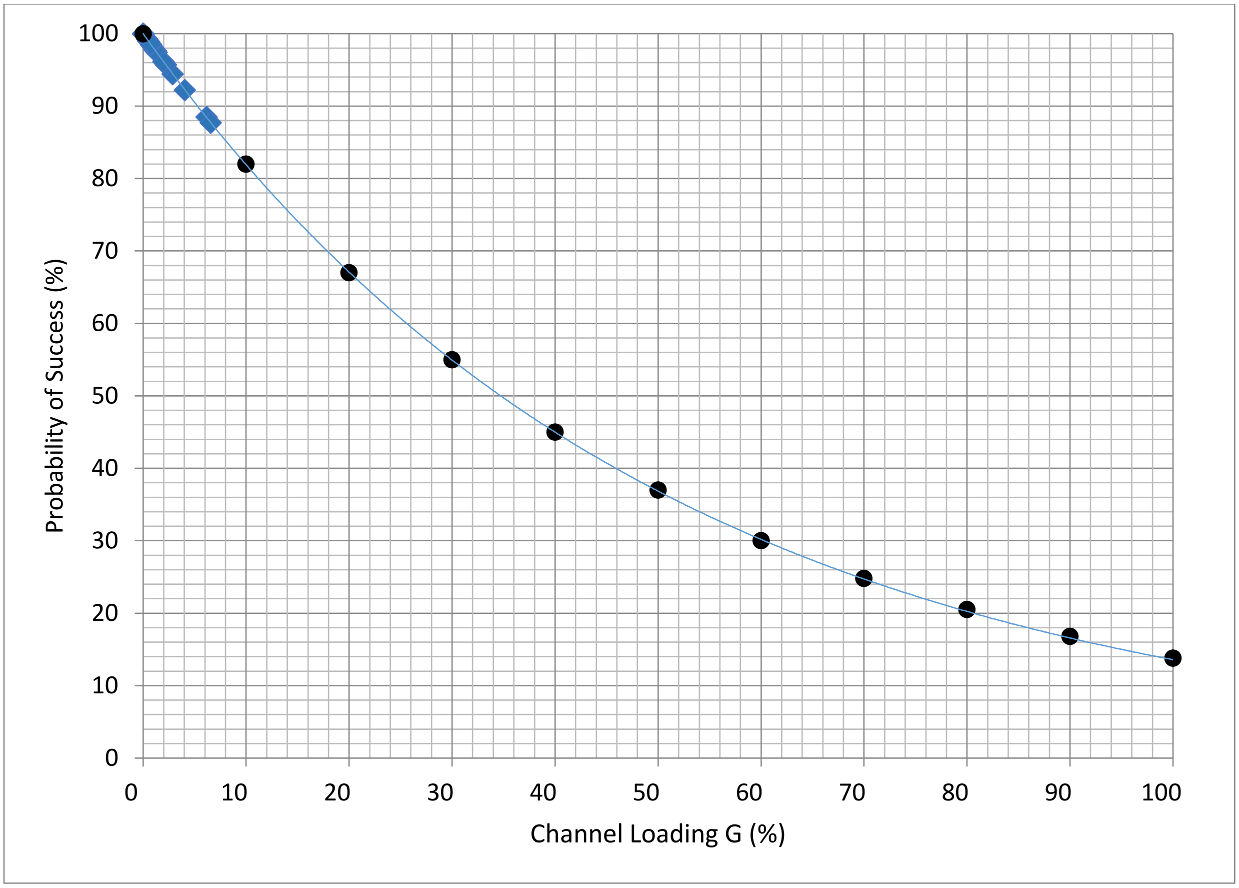

Figure 4: Measured Random Channel Probability of Success

In Figure 4, the blue data points represent the measured channel loading (G) vs. probability of success (p) for valid DCS random channels. Black data points represent what theory predicts for the base case of no repeated transmissions (r = 0), and have been derived from Figure 2. A simple exponential regression trend line generated from the blue data points is a very close fit to what theory predicts. This indicates that any increase in loading on a random channel can also be expected to conform to predictions generated by the theory.

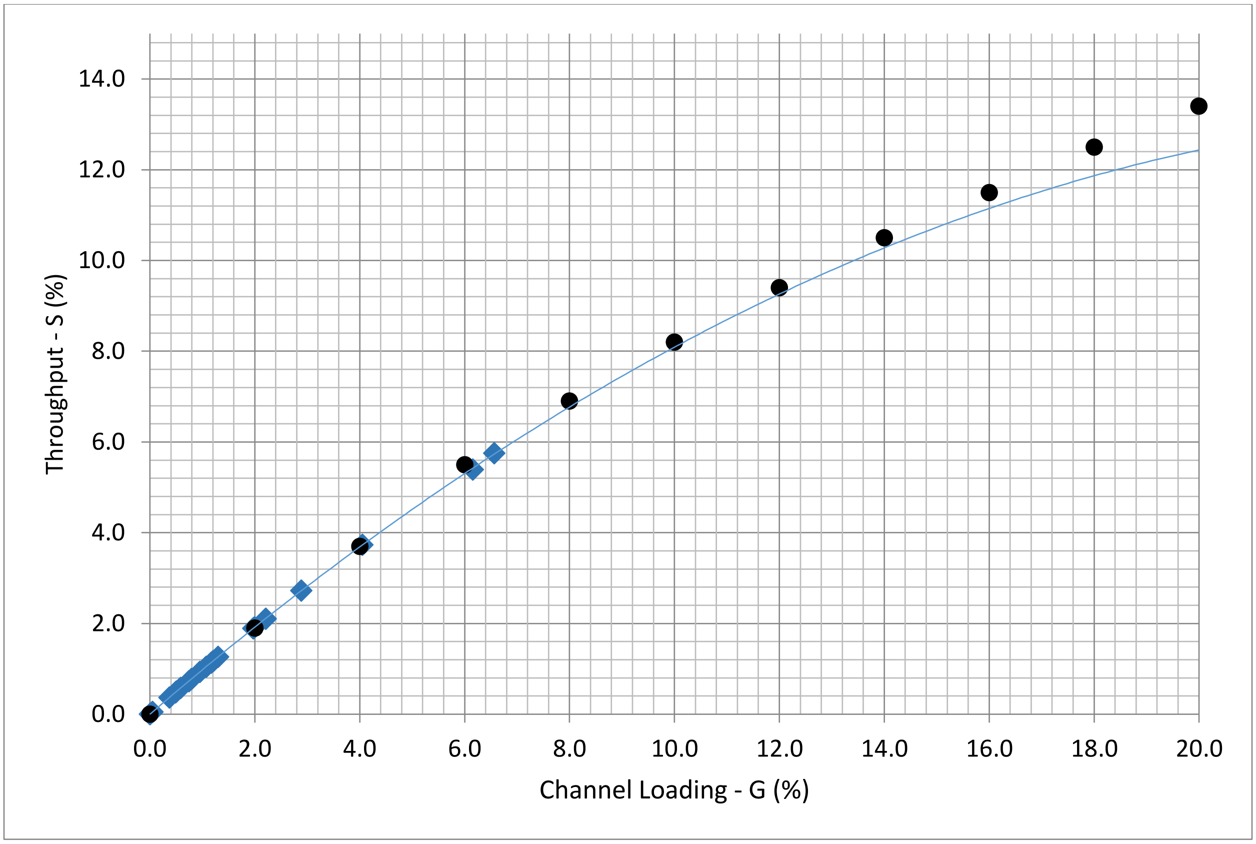

Figure 5: Measured Random Channel Throughput

In Figure 5, the blue data points represent the measured channel loading vs. throughput for valid random channels. Black data points represent what theory predicts for the base case of no repeated transmissions (r = 0), and have been derived from Figure 3. Unfortunately, the polynomial regressions performed on the data did not produce a trend line that agreed with theory for all values of channel loading. However, a 2nd order polynomial regression does produce a trend line that performs reasonably well up to a channel loading of about 20%, after which it deviates wildly from theory. As a result, the plot for the comparison of channel loading (G) and throughput (S) is stopped at that point.

Table 5: Measured DCS Random Channel Transmission Parameters

Random Channel Number	Assumed Active Number of DCPs, N	Message Duration in Seconds		Total Channel Transmission Rate λ_t' messages/hour
		Average	Std. Dev.	
104	40	2.35	0.317	41.50
114	159	0.11	0.000	0.12
115	1338	1.27	0.310	41.23
118	1429	1.37	0.459	53.19
119	1565	1.29	0.296	41.34
120	202	1.28	0.166	5.26
121[4]	1207	1.31	0.253	150.07
123	585	0.48	0.011	0.91
124	1086	1.15	0.230	11.82
125	2681	1.16	0.250	62.82
126	1422	1.24	0.171	14.47
127	1628	1.15	0.158	37.57
128	1159	1.34	0.316	25.35
129	1428	1.41	0.629	32.54
130	2899	1.16	0.257	60.88
131	2122	1.45	0.412	108.14
132	1382	1.22	0.259	21.23
133	1162	1.14	0.191	19.67
134	56	2.38	0.949	93.71
135	1131	1.60	1.186	24.25
136	508	0.24	0.000	0.21

[4] At the time this report was written, channel 121 was experiencing interference that corrupted its recorded data. This channel was ignored for the analysis in this report.

Table 6: Calculated DCS Random Channel Performance Parameters

Random Channel Number	Total Channel Transmission Rate λ_t' messages/hour	Average Channel Loading (%)	Average Channel Throughput (Msgs / T)	Average Probability of Success (%)
104	41.50	2.88	2.7	94.4
114	0.12	0.00	0.0	99.9
115	41.23	1.07	1.0	97.9
118	53.19	1.97	1.9	96.1
119	41.34	1.21	1.2	97.6
120	5.26	0.49	0.5	99.0
121[5]	150.07	6.15	5.4	88.5
123	0.91	0.05	0.1	99.9
124	11.82	0.37	0.4	99.3
125	62.82	2.21	2.1	95.7
126	14.47	0.51	0.5	98.9
127	37.57	1.17	1.1	97.7
128	25.35	0.95	0.9	98.1
129	32.54	1.30	1.3	97.4
130	60.88	1.99	1.9	96.1
131	108.14	4.05	3.7	92.2
132	21.23	0.79	0.8	98.4
133	19.67	0.59	0.6	98.8
134	93.71	6.56	5.8	87.7
135	24.25	0.74	0.7	98.5
136	0.21	0.01	0.1	99.9

[5] At the time this report was written, channel 121 was experiencing interference that corrupted its recorded data. This channel was ignored for the analysis in this report.

Chapter 5: DCS Data Dissemination

DCS data flows through a number of systems and interfaces. The DADDS system receives DCP message data from the existing Microcom DCS Acquisition and Monitoring System – New Technology (DAMS-NT) demodulators. DADDS processes, stores, and distributes data through several interfaces including: HRIT rebroadcast, National Weather Service Telecommunications Gateway (NWSTG), Local Readout Ground System (LRGS) interface using the DDS protocol, and DCS websites.

Appendix 1: Statistical Analysis Assumptions

To analyze the performance of an individual random reporting channel, it is necessary to make some assumptions about the nature of the channel and the traffic (messages) that are to be transmitted on the channel. These assumptions are:

1) The probability of a bit error is small enough to be insignificant. Although this is a satellite channel, the relatively high signal-to-noise ratio ensures that bit errors will be infrequent. For instance, with an un-coded bit error rate of 1×10^{-6} and a bit rate of 300 bits-per-second, a DCP random channel that is utilized 20% of the time could expect a single bit error approximately once every 4.5 hours[6].
2) In accordance with the law of large numbers, if the number of message sources, i.e. the number of DCPs, that are transmitting random reporting messages on a particular channel is large, then their individual DCP message transmission rates, referred to as "arrival rates" in queuing theory, can be summed into an aggregate transmission rate for the purpose of analysis. It is generally agreed in probability theory that the number of sources, in this case DCPs, necessary to use this assumption must be greater than 30. The statistics of the aggregate transmission rate are stationary which ensures the aggregate transmission rate will be a constant. The individual transmission rates will likely be different and will not necessarily be stationary. These characteristics match the behavior of DCPs. Individual DCPs may transmit random reports at different rates, and may, at different times, experience fluctuations in those rates. With this assumption the aggregate channel transmission rate is defined for N > 30 message transmitters, each with individual transmission rates, λ_n, as:

$$\lambda = \sum_{n=1}^{N} \lambda_n = constant \qquad (A1).$$

3) The DCPs transmit independently of each other. This ensures low correlation between transmission events on the channel. If more than one DCP is monitoring the same environmental phenomenon, then an event that triggers more than one DCP to transmit at the same time must be mitigated. An example mitigation method currently used by many DCPs is to include a random delay between the triggering event and original message transmission.
4) Sequential message transmissions from an individual DCP are statistically independent from each other. If triggering events are independent from each other, then individual messages would also be independent. However, if multiple redundant messages are used to improve the probability of successfully delivering the original message, statistical independence must be simulated by including a random delay component in the interval between the redundant messages.

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[6] It takes approximately 4.5 hours to transmit one million bits at a bit rate of 300 bps but only 20% time utilization.

5) Since messages are independent of each other, the time interval between any two transmissions conforms to a Poisson random process that can be used to determine the probability of K messages being transmitted in the time interval τ, assuming a message transmission rate of λ. The probability is given as (Sklar, 1988, p. 499):

$$P(K) = \frac{(\lambda\tau)^K e^{-\lambda\tau}}{K!} \quad K \geq 0 \qquad\qquad (A2).$$

6) Random reporting messages on a random channel are all the same length in time. The current DCPRS Certification Standards (CS2) state that the maximum length of transmission for a random reporting channel that operates at 300 baud is 3 seconds. (NOAA, June 2009). While CS2 compliant 300 baud random reporting messages can be transmitted with durations between a minimum of approximately 0.75 seconds and a maximum of 3 seconds, for the purpose of analysis, the time duration of all messages on a particular channel is fixed at the same length.
7) The time interval between any two messages is, on average, much greater than the length of random reporting messages on the channel. In the original ALOHA system[7], the ratio of interval to message length was 2000 to 1 (Abramson, Packet switching with satellites, 1973). As the first example of packet switched, random-access communications on a satellite channel, this is clearly an example of very low channel efficiency, but the importance of large intervals between messages must be recognized. This assumption also applies for any repeat or redundant messages sent from the same source (Abramson & Kuo, 1973, p. 511). In fact, Abramson & Kuo state that if this assumption is met, then the type of random distribution used to create the interval for redundant messages is not critical.

[7] The DCS random reporting channel is a variant of the ALOHA satellite communication systems.

Appendix 2: Performance Analysis

Appendix 2.1: Introduction

The DCS random reporting scheme is fundamentally based on the ALOHA system developed to extend the United States Advanced Research Projects Agency (ARPA) nationwide circuit-switched terrestrial network to the University of Hawaii inter-island campuses via a packet switched satellite communications channel in 1971 (Abramson, 2009). The ALOHA system, as well as DCS random reporting, are both considered examples of communication schemes known as Demand-Assignment Multiple Access (DAMA). The two main features of DAMA schemes are that they permit multiple users to communicate on a single channel, and they permit on-demand access to the communications resource. While the two schemes use different redundancy processes, the same basic theory applies, and the performance of the ALOHA system will be explained before analyzing the performance of the DCS random reporting mechanism.

The message sources used by these schemes create random reporting messages that "arrive" at the satellite channel for transmission at an overall "arrival rate", or transmission rate of λ messages per unit of time. The term *arrival rate* is an artifact of queuing theory and often used to describe λ, however for satellite communication systems the term *transmission rate* is more appropriate. The units of λ do not specify the unit of time and it is selected to be appropriate for the actual rate. For example, if messages are to be transmitted from a source, on average, once every other minute, the appropriate units for λ might be *messages per hour*.

It is important to note that the channel used by either ALOHA or DCS cannot support any arbitrary original message transmission rate. Depending on the scheme and the required configuration parameters there will be a maximum original message transmission rate that can be supported. Further, in the case of DCS, supporting these maximum original message transmission rates may not correspond to the maximum probability of successfully delivering a message. This infers that the configuration of the DCS random reporting channels should govern the maximum permitted original message transmission rate available to users.

Appendix 2.2: The ALOHA System

In the ALOHA system, message collisions resulted in both stations not receiving an expected acknowledgement, triggering them both to retransmit their message after a random interval (to minimize the chance they would collide again). These retransmissions added traffic to the channel, increasing the total transmission rate to (Sklar, 1988, p. 498)

$$\lambda_t = \lambda + \lambda_r \qquad (A3)$$

where λ_r represents the increase in transmission rate from repeated transmissions. Since λ describes the original message transmission rate, and λ_t describes the total transmission rate with collisions, and since both of these transmission rates have the same unit of time, the ratio of the two transmission rates, λ and λ_t, is equal to the ratio of original messages transmitted and the total messages transmitted. For ALOHA, this ratio is, by definition, the probability of successfully transmitting a message:

$$P_s = \frac{\lambda}{\lambda_t} = \frac{\#\, original\, messages}{\#\, total\, messages} \qquad (A4).$$

This probability can also be derived by reviewing the duration of a message and the duration of the interval between any two messages. If a specific ALOHA station is to transmit a message, a collision will occur if another station, or stations, transmits either right before or right after the specified ALOHA station begins its message transmission. If all messages have a duration of τ, then there is a collision window of 2τ around the specific station's message that no other stations can transmit in if we are to have a successful transmission event for the specific station. If another station begins transmission of its length τ message within the time τ before the specific message begins or at any time τ during the specific message then a collision occurs. The two concatenated τ intervals define the 2τ window of collision protection for a successful transmission.

Using the Poisson random process presented in equation A2, the probability of successfully transmitting a message can therefore be expressed as the probability that no other messages (K=0) are transmitted during the collision protection window of 2τ. The result from Sklar is:

$$P_s = P(K=0) = \frac{(2\tau\lambda_t)^0 e^{-2\tau\lambda_t}}{0!} = e^{-2\tau\lambda_t} \qquad (A5).$$

Setting equations A4 and A5 equal to each other yields:

$$\lambda = \lambda_t e^{-2\tau\lambda_t} \qquad (A6).$$

We pause here to define some necessary terms. The first term we will define is a restatement of the message time duration τ. If the channel can support a bit rate capacity R (usually stated as R bits per second although the time unit can be adjusted as needed), and if each message contains b bits per message, then the message time duration τ can be stated as

$$\tau = \frac{b}{R} \quad \frac{time\ units}{message} \qquad (A7).$$

Next, we define the throughput of the channel, normalized for the capacity of the channel, as the unit-less quantity

$$S = \frac{b\lambda}{R} = \tau\lambda \qquad (A8).$$

The normalized throughput only includes original traffic (in effect the successful traffic) and has a range of $0 \leq S \leq 1$. It is often given as a percentage and relates the fraction of the channel's capacity that is successfully utilized. Here we see the limitation on the original message rate λ

for the channel. If the channel capacity is fully utilized, the original message rate for the entire channel will reach a maximum at $\lambda = 1/\tau$.

The last term to define is normalized channel loading or normalized total traffic. It relates the total transmission rate to the capacity of the channel with the unit-less relationship

$$G = \frac{b\lambda_t}{R} = \tau\lambda_t \qquad (A9).$$

Here the channel loading can exceed the channel capacity because collisions represent occasions when multiple messages are attempting to transmit at the same time. The channel loading accounts for this over-subscription of the single channel resource. As a result, the normalized channel loading has a range of $0 \leq \mathrm{G} \leq \infty$. It is important to note that large values of G indicate high levels of repeated transmission are occurring. This is generally an undesired condition.

Now returning to the analysis of the ALOHA system, if both sides of equation A6 are multiplied by τ, the result is

$$\tau\lambda = \tau\lambda_t e^{-2\tau\lambda_t} \qquad (A10).$$

If we substitute equations A8 and A9 into equation A10 the result relates normalized throughput to normalized channel loading as

$$\mathrm{S} = \mathrm{G}e^{-2\mathrm{G}} \qquad (A11).$$

This result is shown graphically in Figure A1. We note in Figure A1 the maximum throughput of 18.4% that occurs when the channel loading is at 50% of the capacity of the channel.

Next we substitute equation A9 into equation A5 so we can relate the probability of successfully transmitting a message on a single attempt to the channel loading using

$$P_s = e^{-2\mathrm{G}} \qquad (A12).$$

This result is shown graphically in Figure A2. The probability of success decreases exponentially as the channel loading increases. We note the academic case that the probability of success for a single message attempt is 1 only if there is no channel loading.

The probability of success is less than 100% for an individual message, however ALOHA addresses this by repeating transmissions until a successful transmission is completed (yielding a transactional probability of success of 100% for the combination of an individual original message and all of its necessary redundant copies). This has the obvious circular problem of collisions leading to more repeated transmissions leading to more collisions. A runaway overload of the channel was avoided with ALOHA by keeping the channel loading below 0.5. This required transmitters to limit their original message transmission rate and duration so that the channel throughput stayed below 18.4%. This coordination is necessary for DCS as well.

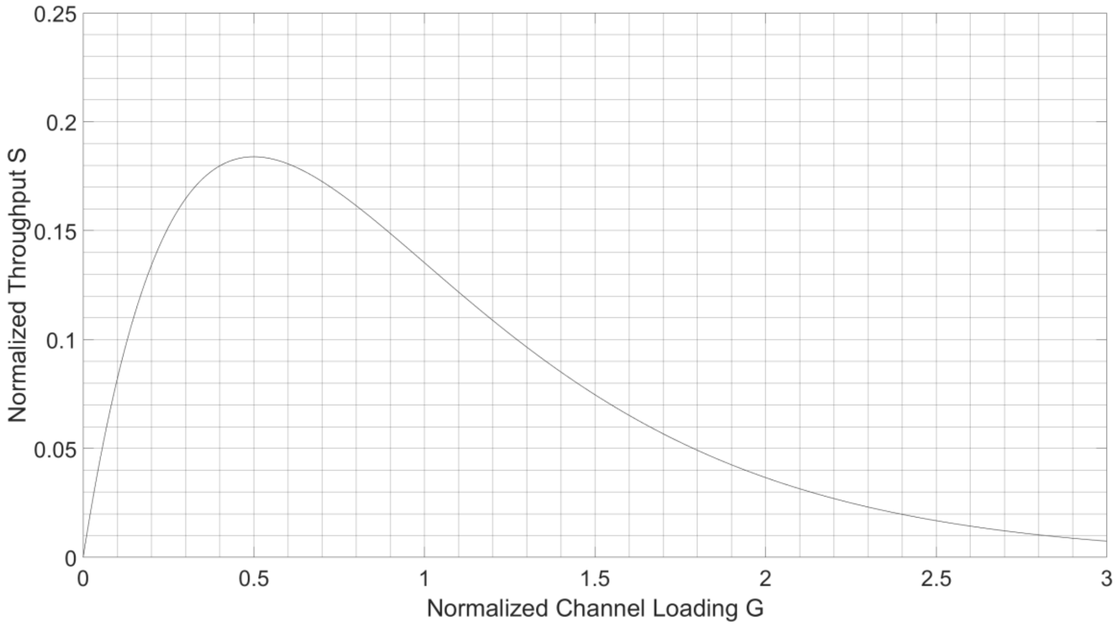

Figure A1: ALOHA System Normalized Throughput

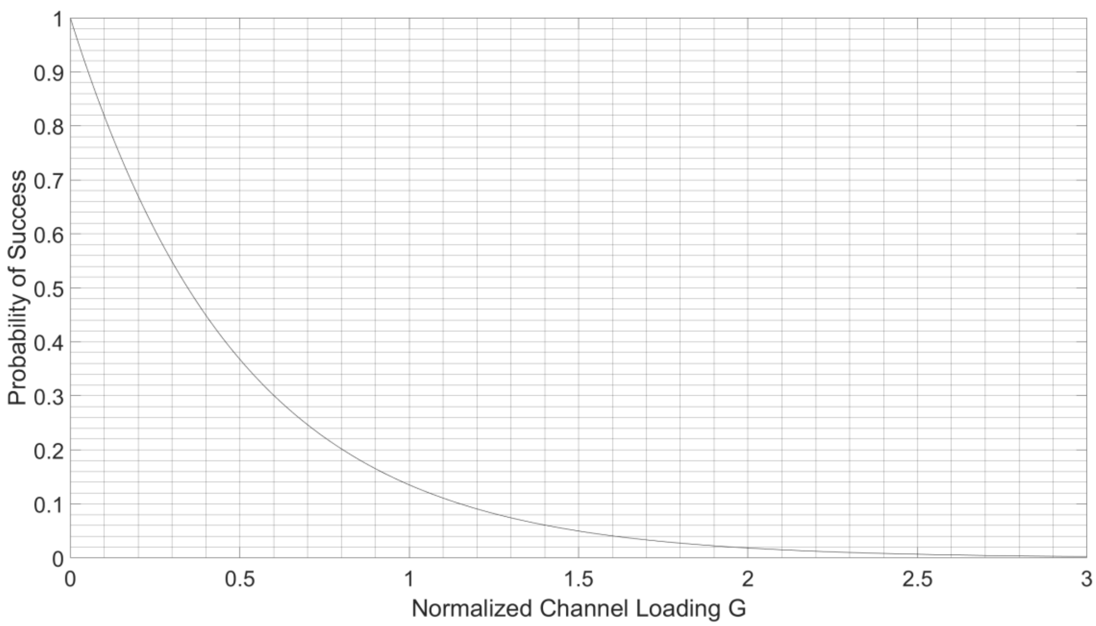

Figure A2: ALOHA System Probability of Success

Appendix 2.3: The DCS Random Reporting Scheme

Having derived the two important performance relationships for the ALOHA system (throughput and probability of success) we can apply a similar analysis to the DCP random reporting scheme. In the predominant form of the DCP random reporting scheme redundant messages are transmitted whether a collision occurs or not. The number of these redundant messages r impacts the total transmission rate. The modified total transmission rate equation is therefore expressed as

$$\lambda_t' = \mathrm{r}\lambda \qquad (A13)$$

where again λ is the original message transmission rate.

The probability of successfully transmitting a message, as stated above in equation A4 for the ALOHA system, cannot be used in this scheme because the total transmission rate, λ_t', is not dependent on the number of collisions. However, the probability of successfully transmitting each of the individual r redundant messages is still defined by equation A5. It is restated here with the new DCP random reporting message total transmission rate and with an indication that the probability is for successfully transmitting one individual message without consideration for redundancy

$$P_{s1} = P(K=0) = \frac{(2\tau\lambda_t')^0 e^{-2\tau\lambda_t'}}{0!} = e^{-2\tau\lambda_t'} \qquad (A14).$$

To find the probability of successfully transmitting at least one of the individual r DCP random reporting messages we use the result from A14 and conduct r independent Bernoulli trials. Considered together, the results of these trials produce a random variable that describes the probability that exactly k successful transmissions will occur in r trials. The random variable has a binomial distribution. Since any number of successes will result in declaring a successful transmission of the original message and all the combinations of successes must be included, a more simple solution is to use the binomial distribution to ask the question "what is the probability of exactly zero successes in r trials", which is the only combination of trial results that corresponds to a failure to transmit the original message. This probability of failure is then subtracted from 1 to find the probability of success. We proceed by introducing the binomial distribution probability function with the appropriate number of trials, r, and the probability of success for a single trial, P_{s1},

$$P(k) = \frac{(r)!}{k!\,(r-k)!} P_{s1}^k (1-P_{s1})^{r-k} \qquad (A15).$$

To find the probability of exactly zero successes we evaluate equation A15 with k = 0, which reduces the equation to

$$P(k=0) = (1-P_{s1})^r \qquad (A16).$$

Since this is the probability of failure, the probability of success can be expressed using first A16 and then A14 as

$$P_s' = 1-(1-P_{s1})^r = 1-\left(1-e^{-2\tau\lambda_t'}\right)^r \qquad (A17).$$

To develop the results further, we again need to introduce some definitions. The same definition for the message time duration τ presented in equation A7 for the ALOHA system is appropriate for the DCS random reporting scheme but the normalized channel loading equation is restated with the new DCS random reporting total transmission rate as

$$G' = \frac{b\lambda_t'}{R} = \tau\lambda_t' = \mathrm{r}\tau\lambda \qquad (A18).$$

We must review the limits for this new normalized channel loading definition. As we will show, $\tau\lambda$ now represents the throughput if no transmission failures occur and it is bounded by the channel capacity to the range of $0 \leq \tau\lambda \leq 1$. We can see that the new normalized channel loading is also now bounded by the new range of $0 \leq G' \leq r$. The implication of the redundancy scheme implemented in DCS random reporting is that the channel loading cannot become infinite due to collisions as was the case with the ALOHA system. In fact, as we have shown, the normalized channel loading for DCS random reporting is specifically limited by the number of redundant message transmissions that are made.

This new normalized channel loading result allows us to reduce the equation for the probability of success in A17 to

$$P_S' = 1 - \left(1 - e^{-2G'}\right)^r \qquad (A19).$$

This equation is shown graphically for values of r between 1 and 5 in Figure A3. We note first that the channel loading range of values increases as r increases, consistent with the bounds on equation A18. The improvement in the probability of success is evident in the graph by the change in shape and movement of the curve to the right as r increases. An important feature in Figure A3 is the increasing insensitivity to small variations in channel loading that occurs near the origin, as r increases. In this region of small channel loading and high probability of success, the probability of success remains highest as the channel loading increases, for increased values of r.

The throughput calculation for the DCS random reporting scheme is not as straight forward as was shown for the ALOHA system. In the ALOHA system it is assumed that every message was eventually delivered, no matter how many redundant messages were needed to successfully deliver the original message. In the DCS random reporting scheme there is a finite probability (less than 1) that the message will be delivered, and it is defined above by equation A17. Since the original message transmission rate is λ and we know that with probability P_S' these messages will be delivered, the normalized throughput equation A8 can be rewritten for DCS random reporting as

$$S' = P_S'\tau\lambda \qquad (A20).$$

If it were possible to guarantee delivery of each message in the DCS random reporting scheme, we can see that the probability of success would equate to 1 and equation A20 would match equation A8. In reviewing equation A8 we can now see that for the ALOHA system the repeated attempts to transmit the message eventually succeed (even if an infinite number of attempts are needed) and so the cumulative, transactional probability of success after sufficient retries is always in fact 1. Remember that for the ALOHA system, the stated probability of success, P_S, in equations A4, A5, and A12 is for an individual message transmission attempt.

Recalling the relationship between the original DCS message transmission rate and the total message transmission rate expressed in equation A13 we can rewrite the normalized throughput equation A20 as

$$S' = \frac{P_s' \tau \lambda_t'}{r} \qquad (A21).$$

Inserting equations A18 and A19 into A21 creates the desired relationship between normalized throughput and normalized channel loading for the DCS random reporting scheme

$$S' = \frac{\left[1 - \left(1 - e^{-2G'}\right)^r\right] G'}{r} \qquad (A22).$$

A graph of the throughput for values of r ranging from 1 to 5 is shown in Figure A4. As expected, introducing additional redundant messages impacts the throughput. For a given constant normalized channel loading G', the normalized throughput S' decreases as r increase. This occurs because the channel loading is carrying more redundant messages and less original messages. Some critical values from the two Figures are presented in Tables A1 and A2. An important benchmark for many DCS users is the need to maintain a probability of success of $P_s' = 95\%$. In Table A1, values of the normalized channel loading, G', that correspond to this probability are shown for values of r between 1 and 5. In addition, Table A2 shows the values of the normalized throughput that correspond to these values of G' (at 95% probability of success). For reference, the maximum possible values of normalized throughput are also shown in Figure A2. Note the differences in what values of normalized channel loading correspond to a high probability of success (95%) verses high throughput.

One of the most important pieces of information in Table A2 is the indication that when operating with a desired probability of success of $P_s' = 95\%$ the optimum number of redundant messages is r = 4. This is noted on the left side of the Table by the peak throughput being achieved when r = 4. This peak value is presented in bold in Table A2.

It is also important to highlight the differences between the ALOHA system and the DCS random reporting scheme. One important difference occurs for the specific case where NO redundant DCS messages are sent, r = 1. In that case, the normalized channel loading G' for DCS random reporting equals $\tau\lambda$. Recall that for the ALOHA system $G = \tau\lambda_t$. The difference in transmission rates is apparent and implies that the channel loading is greater for the ALOHA system. This makes sense when we consider that for the r = 1 case, the DCS random reporting scheme adds no additional messages to the channel to mitigate collisions.

The most important difference between the schemes that should be highlighted is that given the two approaches to redundancy are not related, and in fact one guarantees delivery and the other does not, it is inappropriate to compare their throughput and probability equations on the same graphs. While the graphs may have similar shapes in some circumstances, their independent and dependent variables have different meanings.

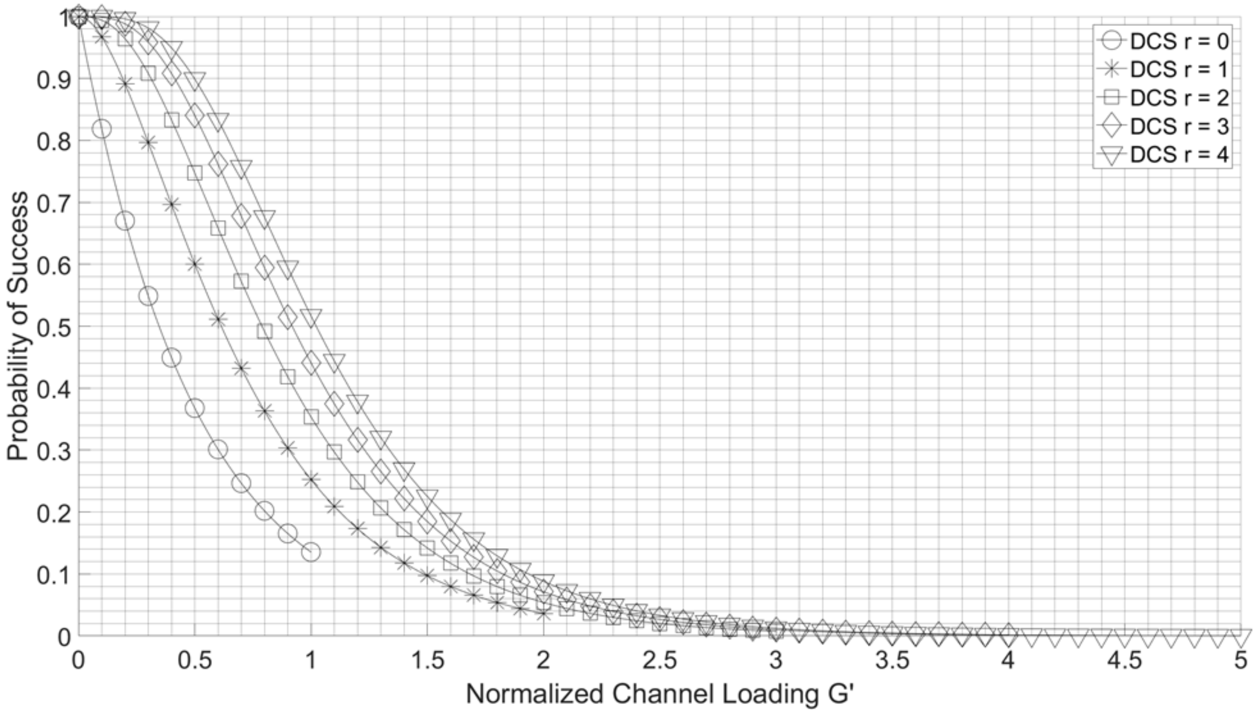

Figure A3: DCS Random Report Probability of Success

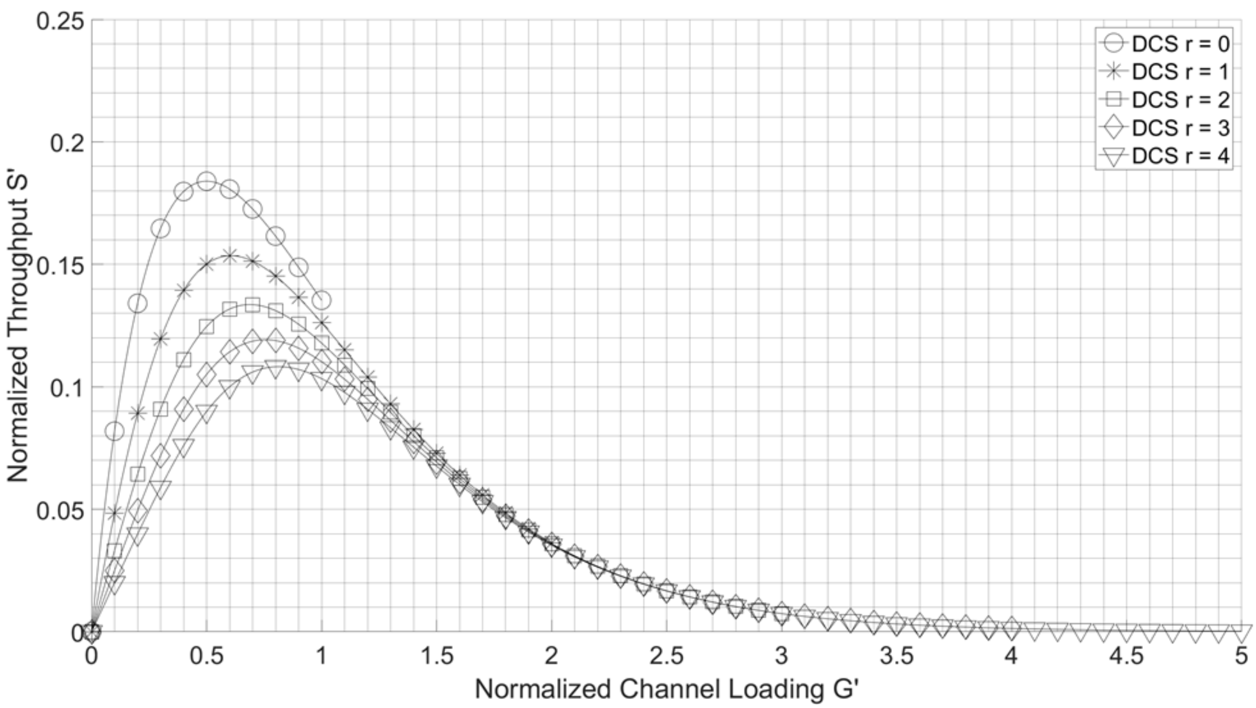

Figure A4: DCS Random Report Normalized Throughput

Table A1: Normalized Channel Loading G', Assuming $P_s' = 95\%$

Number of Repeated Messages	Normalized Channel Loading G' For $P_s' = 95\%$
r = 1	0.025
r = 2	0.126
r = 3	0.229
r = 4	0.320
r = 5	0.398

Table A2: Normalized Channel Loading, G', and Throughput S'

	Assuming $P_s' = 95\%$		Assuming Maximum Normalized Throughput S'		
Number of Repeated Messages	Normalized Channel Loading G'	Normalized Throughput S'	Normalized Channel Loading G'	Maximum Normalized Throughput S'	Probability of Success P_s'
r = 1	0.025	0.0238	0.500	0.1839	36.8%
r = 2	0.126	0.0599	0.606	0.1535	50.7%
r = 3	0.229	0.0725	0.688	0.1336	58.2%
r = 4	0.320	0.0760	0.755	0.1192	63.2%
r = 5	0.398	0.0756	0.813	0.1082	66.6%

Appendix 3: Maximum Number of DCPs Per Channel

The maximum number of DCPs that can be assigned to a channel can be estimated if we restrict the assumption in Appendix 1 regarding the statistics of individual message sources (Assumption 2). If we state that the statistics of all message sources are identical then equation A1 reduces to

$$\lambda = \sum_{n=1}^{N} \lambda_n = N\lambda_n \qquad (A23).$$

The modified total transmission rate in equation A13 is similarly restated as

$$\lambda_t' = \mathrm{r}\lambda = rN\lambda_n \qquad (A24).$$

This results in a restated normalized channel loading from (A18) of

$$G' = \tau\lambda_t' = \mathrm{r}\tau\lambda = \mathrm{r}\tau N\lambda_n \qquad (A25)$$

This last equation introduces the number of message sources N, i.e., the number of DCPs, into the equation for normalized channel loading. Note the interactions between the parameters in equation A25. For a given message duration, τ, if the normalized channel loading is fixed to provide a desired probability of success or a desired throughput then the total transmission rate, λ_t' must be fixed. If we then desire to increase r, the number of repeated transmissions sent from each DCP, we are required to reduce the original channel transmission rate λ to keep λ_t' constant. Reducing λ so we can increase r is only possible if either the number of assigned DCPs, N, or the original individual DCP message transmission rate λ_n is reduced.

This first part of the interaction in equation A25 is captured in Table A3 where the relationship between channel loading, G', and both the total channel transmission rate, λ_t', and the original channel message transmission rate, λ, are shown for a given message duration τ = 3 seconds, and for varying numbers of redundant transmissions r. The normalized throughput is included in Table A3 to emphasize that the performance is optimized when r = 4, if the goal is to achieve 95% probability of success.

We note in the left side of Table A3 (where the goal is to maintain a 95% probability of message transmission success) that although the total channel transmission rate, λ_t', increases monotonically with r, the original message transmission rate peaks when r = 4, corresponding to when the throughput, S', peaks. These peak values are presented in bold in Table A3.

To continue with the examination of the parameter interaction in equation A25, the transmission rate data in Table A3 is used to evaluate the maximum number of DCPs, N, that a channel can support by relating λ to λ_n. The relationship of interest is found by restating equation A23 as

$$N = \lambda/\lambda_n \qquad (A26).$$

Using the critical values of λ found in the left side of Table A3, we can derive the maximum number of DCPs for various values of λ_n, assuming a probability of success of 95% and a message duration of 3 seconds. This data is shown in Table A4. The same equation is used to evaluate the maximum number of DCPs a channel can support at the maximum throughput and these results are shown in Table A5. The optimum redundant message transmission rate of r = 4 when assuming a 95% probability of success is evident in the increased values of N in that column compared to the other columns in Table A4

Table A3: Normalized Channel Loading, G', and Transmission Rate, λ, Messages per Second

	Assuming $P_s' = 95\%$				Assuming Maximum Normalized Throughput S'			
Number of Repeated Messages	Normalized Channel Loading G'	Maximum Normalized Throughput S'	TX Rate λ_t' w/ τ = 3 sec	TX Rate λ w/ τ = 3 sec	Normalized Channel Loading G'	Maximum Normalized Throughput S'	TX Rate λ_t' w/ τ = 3 sec	TX Rate λ w/ τ 3 sec
r = 1	0.025	0.0238	0.0083	0.0083	0.500	0.1839	0.1667	0.1667
r = 2	0.126	0.0599	0.0420	0.0210	0.606	0.1535	0.2020	0.1010
r = 3	0.229	0.0725	0.0763	0.0254	0.688	0.1336	0.2293	0.0764
r = 4	0.320	0.0760	0.1067	0.0267	0.755	0.1192	0.2517	0.0629
r = 5	0.398	0.0756	0.1327	0.0265	0.813	0.1082	0.2710	0.0542

Table A4: Number of DCP Message Sources per Channel Assuming $P_s' = 95\%$

$\tau = 3$ sec	Maximum Number of DCPs Per Random Channel				
Individual DCP λ_n Messages/Hour	Channel $\lambda = 29.9$ Messages/Hour With r = 1	Channel $\lambda = 75.6$ Messages/Hour With r = 2	Channel $\lambda = 91.4$ Messages/Hour With r = 3	Channel $\lambda = 96.1$ Messages/Hour With r = 4	Channel $\lambda = 95.4$ Messages/Hour With r = 5
0.006 (1/wk)	4980	12600	15240	16020	15900
0.021 (1/48hr)	1423	3600	4354	4577	4543
0.041 (1/24hr)	729	1844	2230	2344	2327
0.083 (1/12hr)	360	911	1102	1158	1149
0.167 (1/6hr)	179	453	548	576	571
0.25 (1/4hr)	120	302	366	384	382
0.5 (1/2hr)	60	151	183	192	191
1 / hr	30	76	91	96	95
2 (1/30min)	15	38	46	48	48
3 (1/20min)	10	25	30	32	32
4 (1/15min)	7	19	23	24	24

Table A5: Number of DCP Message Sources per Channel Assuming Maximum Throughput

$\tau = 3\ \mathrm{sec}$	Maximum Number of DCPs Per Random Channel				
Individual DCP λ_n Messages/Hour	Channel $\lambda = 600.1$ Messages/Hour With r = 1	Channel $\lambda = 363.6$ Messages/Hour With r = 2	Channel $\lambda = 275.0$ Messages/Hour With r = 3	Channel $\lambda = 226.4$ Messages/Hour With r = 4	Channel $\lambda = 195.1$ Messages/Hour With r = 5
0.006 (1/wk)	100020	60600	45840	37740	32520
0.021 (1/48hr)	28577	17314	13097	10783	9291
0.041 (1/24hr)	14637	8868	6708	5523	4759
0.083 (1/12hr)	7230	4381	3314	2728	2351
0.167 (1/6hr)	3594	2177	1647	1356	1168
0.25 (1/4hr)	2400	1454	1100	906	780
0.5 (1/2hr)	1200	727	550	453	390
1 / hr	600	364	275	226	195
2 (1/30min)	300	182	138	113	98
3 (1/20min)	200	121	92	75	65
4 (1/15min)	150	91	69	57	49

Appendix 4: Random Delay Interval Assessment

Assumptions 3 and 4 in Appendix 1 discuss the requirement for independence between messages from different sources, and between messages and repeat messages from the same source. Assumption 5 states that the interval between messages should conform to a Poisson probability distribution. Two specific questions that must be answered are:

- How much time should a DCP wait after a triggering event occurs before transmitting the first random reporting channel message?
- How much time should a DCP wait before transmitting the first repeated message, and each subsequent repeated message?

Assumption 3 infers that random reporting messages from different DCPs must be independent of each other. To ensure this happens, we must not allow DCPs monitoring the same environmental phenomenon to transmit immediately upon receipt of a triggering event. Consider the example of multiple seismic sensors that are all equidistant from a geological event that causes an earthquake. It is possible that all of the sensors would attempt to transmit their random reporting message at the same time (within a few seconds of each other), causing congestion on the random channel and the failure of potentially all of the initial messages to be received. If, however, a random delay is inserted to ensure the separate initial messages do not transmit at the same time, then the probability of initial messages colliding with each other is greatly reduced.

Since multiple initial messages caused by the same triggering event must appear independent to each DCP and to previous and subsequent messages from the same DCP, the initial delay should conform to the total transmission rate. This will ensure that a cluster of initial messages (triggered by the same event) will all appear to be similar to any other message. Most DCP vendors implement the random component of their delay intervals using a uniform random distribution. As indicated above in assumption 7 of Appendix 1, as long as the interval is large relative to the message length, the type of probability density function is not critical (Abramson & Kuo, 1973, p. 511).However, in applying queuing theory analysis here, the probability density function to use for generating the delay is the Poisson distribution[8] with a total expected rate of occurrence for the channel of λ_t'. The distribution for an individual DCP would therefore use a reduced expected rate of occurrence that can be found using equation A24 as

$$\lambda_t'/N = r\lambda_n \qquad (A27).$$

Assumption 4 addresses messages from an individual source and the need for independence so that the repeated transmissions appear statistically identical to original messages. Using the same argument as was presented above for assumption 3, we conclude here as well that the ideal distribution for the transmission of original and repeated messages from an individual DCP is a Poisson distribution with a transmission rate of occurrence as given in equation A27. The suggestion that the appropriate rate of transmission to use is the same for both the messages from independent sources and the messages from an individual source means that the two questions asked at the start of this appendix actually have the same answer.

Recalling the desire for an overall message probability of success of 95%, then the maximum normalized channel loading, G', and the associated original message channel transmission rate, λ, are known for each profile of redundant messages, r, that may be chosen. These values were tabulated in the left side of Table A3. Once a redundant number of transmissions r is chosen for the DCPs on the channel and λ is identified in Table A3, Table A4 can be used to analyze the equation $\lambda = N\lambda_n$ and identify a pair of values for the maximum number of DCPs on the channel, N, and the associated maximum DCP original message transmission rate, λ_n. Since NOAA assigns random reporting DCPs to their channels, it is appropriate to review the current number of active assigned DCPs on each random channel to better understand the maximum original transmission rates that are currently available. This data is presented in Table A6. Using equation A27 the data in Table A6 are then converted into individual DCP transmission rate statistics as shown in Table A7. In addition, the various redundant transmission values for r are considered to estimate the individual DCP original message transmission rate, λ_n, used in equation A27.

The current DCS random reporting channel with the highest estimated individual DCP total message transmission rate, λ_t'/N, is channel 134 and is shown in bold in Table A7 with an estimated rate of 1.6733 messages per hour (one message every 36 minutes). However, a more realistic view of the traffic is achieved if we can review the individual DCP original message transmission rate, λ_n, for channel 134. If we assume r = 4, the individual rate is 0.4183 messages per hour, as shown on the same line of Table A7. This rate, (one original message

[8] The Poisson random process is used in queuing theory to describe the arrival statistics of transmissions from independent sources. This is an identical scenario and justifies its use.

approximately every 2.5 hours) lets us profile the redundant messages as occurring in a cluster immediately after the original message is transmitted every 2.5 hours.

With r = 4, the redundant messages can be accommodated and transmitted before the next original message is expected to be transmitted, as long as they are generated faster than once every 36 minutes. Since it is common to use a random delay of approximately 5 minutes (+/-1 minute of random time) before transmitting repeated messages, this is easily accomplished. One final question that arises regarding the interval before an original or redundant message is transmitted is whether the commonly-used 5-minute interval is sufficiently long to ensure all messages appear independent from each other and those of other DCPs.

To answer this question a simulation was created in Mathworks Matlab that analyzes the probability of success for a DCS random channel using several profiles with different message counts in each transaction. The original message transmission rates on the left side of Table A3 are used in the simulator since they correspond to a 95% probability of success with traditional Poisson intervals. In the simulator, two profiles of time intervals are also used. In the first profile the same program delay interval is used before transmitting each message in a transaction. It consists of a 5-minute fixed delay and a +/- 1 minute random delay created using a uniform random variable. In the second modified delay profile, the first delay, between the triggering event and the first message, is cut in half to speed up delivery of the first message. The simulator results are shown in Table A8 and suggest that the program delay intervals are adequate and do not impact the probability of success. In fact, since the simulator results exceed the theoretical estimate for probability of success, it may be that the use of the fixed plus uniform random interval delay profiles make it less likely for collisions to occur between messages than the Poisson distribution does. The simulator source code is shown in Figures A5-A7.

Table A6: DCS Random Channel Assignments and Transmission Rates

Random Channel Number	Number of DCPs Assigned P = Primary Assignment S = Secondary Assignment	Assumed Active Number of DCPs, N	Recorded Total Channel Transmission Rate λ_t' messages/hour
104	15P + 25S = 40	40	41.50
114	0P + 159S = 159	159	0.12
115	0P + 1338S = 1338	1338	41.23
118	0P + 1429S = 1429	1429	53.19
119	0P + 1565S = 1565	1565	41.34
120	0P + 202S = 202	202	5.26
121[9]	0P + 1207S = 1207	1207	150.07
123	0P + 585S = 585	585	0.91
124	0P + 1086S = 1086	1086	11.82
125	0P + 2681S = 2681	2681	62.82
126	20P + 1402S = 1422	1422	14.47
127	0P + 1628S = 1628	1628	37.57
128	0P + 1159S = 1159	1159	25.35
129	0P + 1428S = 1428	1428	32.54
130	0P + 2899S = 2899	2899	60.88
131	1P + 2121S = 2122	2122	108.14
132	2P + 1380S = 1382	1382	21.23
133	0P + 1162S = 1162	1162	19.67
134	50P + 6S = 56	56	93.71
135	0P + 1131S = 1131	1131	24.25
136	1P + 507S = 508	508	0.21

[9] At the time this report was written, channel 121 was experiencing interference that corrupted its recorded data. This channel was ignored for the analysis in this report.

Table A7: Individual DCP Transmission Rates

Random Channel Number	Estimated Individual Channel Transmission Rate $\frac{\lambda_t'}{N} = r\lambda_n$ messages/hour	Individual DCP Original Message Transmission Rate λ_n messages/hour				
		r=1	r=2	r=3	r=4	r=5
104	1.0376	1.0376	0.5188	0.3459	0.2594	0.2075
114	0.0008	0.0008	0.0004	0.0003	0.0002	0.0002
115	0.0308	0.0308	0.0154	0.0103	0.0077	0.0062
118	0.0372	0.0372	0.0186	0.0124	0.0093	0.0074
119	0.0264	0.0264	0.0132	0.0088	0.0066	0.0053
120	0.0261	0.0261	0.0130	0.0087	0.0065	0.0052
121	0.1243	0.1243	0.0622	0.0414	0.0311	0.0249
123	0.0015	0.0015	0.0008	0.0005	0.0004	0.0003
124	0.0109	0.0109	0.0054	0.0036	0.0027	0.0022
125	0.0234	0.0234	0.0117	0.0078	0.0059	0.0047
126	0.0102	0.0102	0.0051	0.0034	0.0025	0.0020
127	0.0231	0.0231	0.0115	0.0077	0.0058	0.0046
128	0.0219	0.0219	0.0109	0.0073	0.0055	0.0044
129	0.0228	0.0228	0.0114	0.0076	0.0057	0.0046
130	0.0210	0.0210	0.0105	0.0070	0.0053	0.0042
131	0.0510	0.0510	0.0255	0.0170	0.0127	0.0102
132	0.0154	0.0154	0.0077	0.0051	0.0038	0.0031
133	0.0169	0.0169	0.0085	0.0056	0.0042	0.0034
134	1.6733	1.6733	0.8367	0.5578	0.4183	0.3347
135	0.0214	0.0214	0.0107	0.0071	0.0054	0.0043
136	0.0004	0.0004	0.0002	0.0001	0.0001	0.0001

Table A8: Interval Delay Simulator Results

# of Messages per transaction	Original message transmission rate in messages per second	Interval Profile	Number of Simulation Trials	Probability of Success
1	0.0083	5min +/-1min	100,000	98.27%
		2.5min +/-.5min		97.87%
2	0.0210	5min +/-1min	100,000	99.80%
		2.5min +/-.5min		99.70%
3	0.0254	5min +/-1min	1,000,000	99.99%
		2.5min +/-.5min		99.96%
4	0.0267	5min +/-1min	10,000,000	99.99941%
		2.5min +/-.5min		99.996%
5	0.0265	5min +/-1min	100,000,000	99.99997%
		2.5min +/-.5min		99.9996%

```
%
% Simulation of NOAA GOES DCS Random Channel – Uses seconds as base time unit.
% Brian Kopp – Created 12/28/2020 – Revised 3/7/2021
%

clear all
rng(7);                                  % fixed seed for uniform random number generator
run_length = 100000000;                  % number of iterations performed by the simulation

%Set parameters; fixed delay in seconds from trigger event until first transmission
first_fix_delay = 5*60;

% bound of +/- random part of the delay in seconds before the first transmission
first_rnd_delay = 1*60;

% fixed delay in seconds before subsequent transmissions
second_fix_delay = 2.5*60;

% bound of +/- random part of the delay in seconds before subsequent transmissions
second_rnd_delay = 0.5*60;

tau = 3; %transmission length in sec
r = 5; %number of transmissions in complete transaction

% define collision storage matrix and load with zeros. Collisions will be stored as a 1. Each row
% stores a complete transaction. Rows with r ones is a failure since all r msgs have collisions.
c=zeros(run_length,r);

% we will maintain a count of failed transactions in this counter
failure_cnt = 0;

% Triggering event tx rate (msgs/sec) for entire channel from table A3. excludes additional transmissions
Channel_lambda=0.0265;

% triggering event will occur at time zero and start sequence for one transaction to be processed.
% separately and concurrently, a Poission distribution determines the start time of the second triggering
% event. The second transaction's timing is then compared with the first's to look for collisions.
% for each transaction the Poisson distribution is computed from a uniform random variable, and
% the transformation to a Poisson distribution requires the following constant which is computed once.
denom=(r)*Channel_lambda;
```

Figure A5: Matlab Script for DCS Random Reporting Performance – Part 1

```
% k is the index for the number of trials performed. each trial will look for failed transactions. ideally the
% number of failed transactions should remain below 5% to show probability of success greater than 95%
for k = 1:run_length

  % generate poission derived start time for the second transaction where x(k) is the start time
  u=rand;
  x(k)= -(log(1-u))/denom

  % clear and reset start times
  f_end_hold = 0;                          % first transaction start time
  s_end_hold = x(k);                       % second transaction start time

  % generate start times for all transmissions in both transactions. initial delay for first transmission can be
  % different for subsequent delays. Find initial start times before looping to find subsequent start times.

  % generate the start time for the first transmission in the first transaction
  f_start(1)=f_end_hold + first_fix_delay + ((rand)*2-1)*first_rnd_delay;

  % add tau to get end time. value used as the reference for next transmission start time
  f_end_hold = f_start(1)+tau;

  % generate the start time for the first transmission in the second transaction
  s_start(1)=s_end_hold + first_fix_delay + ((rand)*2-1)*first_rnd_delay;

  % add tau to get end time. value used as the reference for next transmission start time
  s_end_hold = s_start(1)+tau;

  % now generate the other transmissions using the delays for additional transmissions.
  for r_cnt = 2:r
    f_start(r_cnt)=f_end_hold + second_fix_delay + ((rand)*2-1)*second_rnd_delay;
    f_end_hold = f_start(r_cnt)+tau;

    s_start(r_cnt)=s_end_hold + second_fix_delay + ((rand)*2-1)*second_rnd_delay;
    s_end_hold = s_start(r_cnt)+tau;
  end
```

Figure A6. Matlab Script for DCS Random Channel Performance - Part 2

```
  % we now have all tx start times in f_start() and s_start(), and compare all combinations to look for overlaps
  % if an overlap occurs a collision is declared and an entry is added to the collision matrix.

  % first transaction is used as the reference to check for collisions in transmissions for the first transaction
  % each transmission in the first transaction is checked against all transmissions in the second transaction.

  % a nested loop is used to test msgs from the first and second transactions.  An outer loop steps thru msgs
  % from the first transaction and an inner loop steps thru msgs from the second transaction, which are then
  % compared with msgs from the first transaction to determine if a collision has occurred.

  for r_cnt_first = 1:r                          % cycle thru each tx in the first transaction
    for r_cnt_second = 1:r                       % cycle thru each tx in the second transaction

      % collisions occur if any tx from the second transaction overlaps with the selected transmission from
      %  the first. overlap is a 2* tau window centered on the start time of the first transaction. if the second
      % transaction's transmission starts in that window then a collision occurs, then any of the transmissions
      % in the second can collide. we only need one collision to put a 1 in the collision matrix for the particular
      % need one collision to put a 1 in the collision matrix for transmission from the first transaction. the inner
      %  loop is simple to prevent breaking out of the inner loop if a collision is detected, (but we could).

      if ((s_start(r_cnt_second)>=f_start(r_cnt_first)-tau)&&(s_start(r_cnt_second)<f_start(r_cnt_first)+tau))
        c(k,r_cnt_first)=1;
      end
    end
  end

  % now that collision checking is finished we assess if a failure occurred. if all collision matrix entries in the
  % row corresponding to the kth trial just ran equal 1, then every tx from the first transaction experienced a
  % collision and the failure counter is incremented.

    if (sum(c(k,:))== r)                         % look for times when all r copies experienced collisions
      failure_cnt=failure_cnt+1;
    end
end;

% compute failure count for histogram report to the command line

failure_cnt
failure_cnt*100/run_length

histogram(x)
grid
```

Figure A7. Matlab Script for DCS Random Channel Performance - Part 3

Appendix 5: Performance Analysis Algorithm

The algorithm outlined in this appendix was used to generate the random channel loading, throughput and probability metrics by querying for and analyzing messages from platforms that are active on a given random channel. Multiple nested SQL cursor queries are used to step through all random channels, unit time slots and distinct platforms to obtain data points that are then used to calculate the desired channel metrics.

1. Using an SQL cursor, query for all unit time slots (days, hours, etc.) that will be analyzed. For each unit time slot returned by the query, perform the following:
   - 1.1. Determine the total number of active PDTs
   - 1.2. Query for the total number of messages
   - 1.3. Calculate the average message time (T), which is equal to the sum of all message times divided by the total number of messages.
   - 1.4. Using an SQL cursor, query for all distinct platforms in the unit time slot. For each platform returned by the query, perform the following:
     - 1.4.1. Get the total number of messages for the platform in the unit time slot.
     - 1.4.2. Calculate the platform's individual time average transmission rate.
       - 1.4.2.1. Calculate the 'multiplier', which is equal to the unit time in hours divided by the platform message count for the unit time slot.
       - 1.4.2.2. Calculate the 'divisor', which is equal to the multiplier value times 3600 seconds (the # of seconds in an hour).
       - 1.4.2.3. Calculate the platform's individual lambda value, which is equal to 1 divided by the divisor value.
     - 1.4.3. Add the platform's individual lambda value to the total time average transmission rate (lambda) for the unit time slot.
     - 1.4.4. Go to the next platform returned by the cursor query. Repeat until all platforms have been analyzed.
   - 1.5. Using the time average transmission rate (lambda), calculate the desired random channel metrics for the unit time slot being analyzed.
     - 1.5.1. Calculate channel loading (G), which is equal to the time average transmission rate (lambda) multiplied by the average message time (T) for the channel and time slot.
     - 1.5.2. Calculate channel throughput (S), which is equal to the channel loading multiplied by the natural log raised to -2 multiplied by the channel loading value.
     - 1.5.3. Calculate the probability of a successful transmission, which is equal to the natural log raised to -2 multiplied by the channel loading value.
   - 1.6. Go to the next unit time slot returned by the cursor query. Repeat until all unit time slots have been analyzed.
2. Go to the next channel returned by the cursor query. Repeat until all channels have been analyzed.

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